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Fermilab Muon Collider Task Force

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Abstract. A summary is given of results from the first year of Muon Collider Task Force activities.

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INTRODUCTION

Muon Colliders offer a possible long term path to lepton-lepton collisions at center-of-mass energies $\sqrt{s} \geq 1$ TeV. In October 2006 the Muon Collider Task Force (MCTF) proposed [1] a program of advanced accelerator R&D aimed at developing the Muon Collider concept. The proposed R&D program was motivated by progress on Muon Collider design in general, and in particular, by new ideas that have emerged on muon cooling channel design. The scope of the proposed MCTF R&D program includes muon collider design studies, helical cooling channel design and simulation, high temperature superconducting solenoid studies, an experimental program using beams to test cooling channel rf cavities and a 6D cooling demonstration channel.

Muon Collider Design Studies

An important goal for the MCTF activity is, within the next two to three years, to establish one or more realizable muon collider parameter set(s), and hence identify the performance goals for the muon cooling channel. Past physics studies have shown that a Muon Collider with $\sqrt{s}$ = 1 TeV to a few TeV requires a minimum luminosity of $\sim 10^{34}$ cm^{-2} s^{-1} to probe with adequate sensitivity the physics beyond the Standard Model. Two design strategies are being investigated to achieve this luminosity. In the "high-emittance" strategy the muons of each sign are packaged in the minimum number of bunches (one per cycle) and the emittance goal corresponds to the beam-beam limit. In the "low-emittance" strategy the muons are packaged into many bunches with much lower transverse emittances. To establish the feasibility of the high- and/or low-emittance schemes it is necessary to establish the existence of corresponding Collider Lattice designs that assume realistic parameters for magnets, rf, etc. Ring studies this year explored various lattices, paying attention to chromatic correction and momentum acceptance. The designs for the high-emittance lattice are close to achieving the desired momentum acceptance and dynamic aperture, although further studies are needed. However, new ideas are needed to achieve a ring design that corresponds to the low emittance collider scheme.

Cooling Channel Design and Simulation

In addition to different collider design strategies (low- or high-emittance), different cooling channel technologies are also being explored. Ionization cooling reduces the beams transverse phase space. To achieve 6D cooling requires also mixing the longitudinal and transverse degrees of freedom, which can be achieved using an arrangement of helical solenoids. Two helical solenoid schemes are being pursued. The "Guggenheim" scheme has been developed over the last couple of years by the NFMCC. Its proponents are also members of the MCTF, and are continuing to further develop the Guggenheim design and understand its performance and limitations. The newer Helical Cooling Channel (HCC) scheme was proposed by members of Muons Inc. Since it is newer, the HCC design studies are less well advanced, and have been a focus of attention during the first year of MCTF activities. During this year HCC simulation studies have begun to explore various ways of integrating RF cavities into the channel, and also begun to explore the design of a high-field HCC section at the end of the channel which enables lower emittances to be achieved. The results of these studies are promising and, although many details still need to be understood, both HCC and Guggenheim channels could in principal be used to achieve the emittances required for the high-emittance Muon Collider scheme. The low emittance scheme will require something extra, beyond either an HCC or a Guggenheim channel. The additional cooling idea that is being explored has been called Phase Ionization Cooling (PIC). Although there has been progress on developing the PIC concept it is not yet sufficiently well understood to enable design studies to begin based on tracking simulations of a PIC channel. Further PIC studies must be pursued in the coming year.

High Pressure RF Studies

The present designs for the phase rotation and cooling channels require high gradient RF cavities to operate in magnetic fields of up to a few Tesla. MUCOOL R&D has shown that vacuum pillbox cavities breakdown at lower gradients when operated in a magnetic field. The continuing MUCOOL R&D program is exploring ways to mitigate this effect, using alternative materials, surface treatments, and magnetic geometries. Previous measurements with open cell vacuum cavities showed no significant performance degradation in a magnetic field, however open cell cavities require a doubling of the required peak rf power and a corresponding increase in cost. Muons Inc. has proposed an alternative and potentially cost effective solution using cavities filled with high pressure gas to both suppress breakdown and provide the energy loss absorber. A High Pressure RF (HPRF) test cell has been shown to operate in a magnetic field with no appreciable reduction in the achievable RF gradient. However, these tests were made in the absence of an ionizing beam. The next significant step towards understanding the viability of a cooling channel using HPRF cavities is to study operation in an ionizing beam of appropriate intensity. The main focus of the MCTF RF activities in the last year has been to prepare a HPRF beam test in the MUCOOL Test Area (MTA). This requires extracting a linac beam and transporting it to the MTA. In the last year the beamline design has been completed, beamline components are have been refurbished and refitted, and four new elements built and installed: two identical beam stops and two extraction magnets (C-magnets). The beamline, instrumentation and vacuum elements, as well as utility systems, have also been installed. Completing the MTA beam capability and making the first HPRF test with beam is a priority for our MCTF activities in the coming year.

HCC Solenoid Development

The HCC requires the development of an appropriate magnet system. Two conceptually different designs have been investigated. The first is the large bore "conventional" design which consists of a solenoid coil with separate helical dipole and quadrupole coils wrapped around it. The second is a small bore "helical solenoid" consisting of many individual coils arranged in a helical pattern. The helical dipole and quadrupole components are generated by the coil offsets and radii. The helical solenoid version introduces some design constraints, but is significantly easier and cheaper to build, and has emerged as the preferred solution. As a first step toward building a helical solenoid magnet that can be tested in a beam, it is planned to build a subscale model with four solenoid coils that fits within the Technical Division Vertical Magnet Test Facility (VMTF) Dewar. The mechanical support structure for the test coils will also simulate the geometry of the solenoids in the real magnet. A magnetic measurement system will be developed to characterize the model magnet, validate the fields, and monitor field stability during current excitation.

Cooling Experiment

An important part of the proposed future MCTF program is to perform an experimental test of the HCC theory, technology, and simulations. This will require developing and bench-testing HCC components, integrating them into a short test channel, and measuring the response of a muon beam to the channel. An alternative approach has also been proposed in which the component development and beam experiment are separated so that the experiment (MANX) demonstrates cooling with a cheaper HCC system that therefore does not use the components developed to demonstrate the viability and performance of HCC hardware. Which approach is optimal will depend upon costs, timescales and budgets. In the last year the MANX concept has been further developed and possible muon beams at Fermilab investigated. Further work must be done in the coming year to better understand the cost of implementing a muon beam, the cost of the MANX experiment, the cost of developing HCC components, and the cost of the alternative to MANX in which the developed HCC components are assembled into a short cooling section and tested in a beam.

HTS Conductor and Solenoid Studies

The final Muon Collider cooling channel stages may require DC solenoid magnets with magnetic fields of 40-50 T in an aperture of ~50 mm. A 45 T hybrid solenoid with superconducting outer coils and copper inner coils has been successfully built and operated at NHMFL, however, the ~30 MW power consumption at the maximum field makes this magnet design unattractive, and perhaps impractical, for accelerator applications. A potentially more attractive solution is to use HTS conductor. To guide the design and simulation studies for the final cooling stages requires an initial HTS conductor and magnet R&D activity to evaluate the practicality of developing high-field HTS solenoids, and assess the likely associated operating parameters. In the past 12 months studies have been performed on two kinds of HTS materials: BSCCO-2212 as a round multifilamentary wire, and anisotropic conductors, (BSCCO-2223 and second generation coated conductors YBCO). For the BSCCO-2212, tests have been performed to study the effects of J_c from billet preparation and cabling parameters, primarily at 4.2 K, along with SEM/EDS analysis. For the anisotropic conductors studies were performed on the angular dependence of the J_c using a newly designed probe. All studies were performed in the Superconductor R&D laboratory in the Fermilab Technical Division magnet systems department. In addition to conductor studies, HTS solenoid structural analysis and analytical optimization studies have been started to find an acceptable solution for the field, stresses and cost. Quench protection concepts are also being investigated. These studies will continue in the coming year, and should provide the basis for formulating a longer-term R&D program and evaluating the likely properties of an HTS high-field solenoid build for a muon cooling channel.

Summary

In its first year the MCTF has made progress on (i) Muon Collider ring studies, (ii) 6D cooling channel design and simulation studies with an emphasis on the HCC scheme, (iii) beam preparations for the first HPRF cavity beam test, (iv) preparations for an HCC four-coil test, (v) further development of the MANX experiment ideas and studies of the muon beam possibilities at Fermilab, (vi) studies of how to integrate RF into an HCC in preparation for a component development program, and (vii) HTS conductor and magnet studies to prepare for an evaluation of the prospects for of an HTS high-field solenoid build for a muon cooling channel.

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REFERENCES

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